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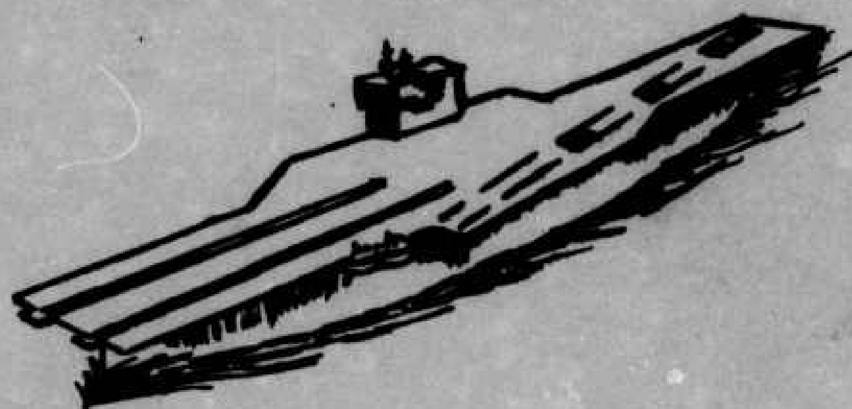
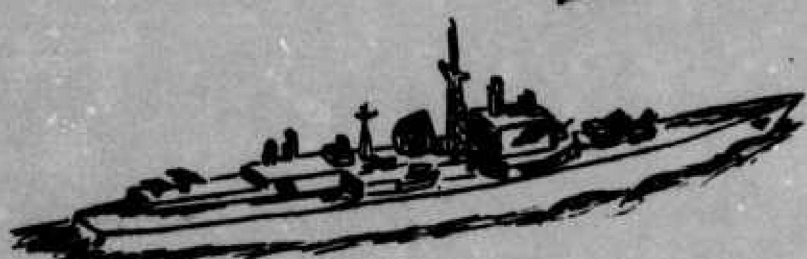
COLLISION AVOIDANCE DEVICES ON BOARD U.S. NAVY SHIPS





COMMANDER CRUISER DESTROYER GROUP TWO/
DESTROYER DEVELOPMENT GROUP
TECHNICAL REPORT No. 2-75

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1. Reference (a) assigned the project of evaluating the concept of utilizing collision avoidance devices onboard U.S. Navy Ships. Enclosure (1), the final report of that concept evaluation, is forwarded for information.

S. L. GRAVELY, JR.

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COLLISION AVOIDANCE DEVICES

ONBOARD

U.S. NAVY SHIPS

COMCRUDESGRU TWO/DESDEVGRU

TECHNICAL REPORT NO. 2-75

Submitted by: LCDR S.G. Kmetz, USN

Approved by:

It was found, however, that no one device provided all the desired features. As is expected between different models and manufacturers, various degrees of success were reported. These devices, however, generally provided substantial assistance in the shipboard collision avoidance function. It is this concept and the possibility of adaptation to U.S. Naval ships that stimulated investigation.

During 1971, the Destroyer Development Group began examination of the application possibilities of automated collision avoidance devices for the Navy. After preliminary study, it was considered that such equipment may have suitable application to naval use and could possibly improve the efficiency of the bridge watch on destroyers. In July 1972, a DIGIPLOT collision avoidance device manufactured by Iotron Corporation was purchased for fleet evaluation. Procurement was funded by the Navy Science Assistance Program (NSAP) and the device was installed on the USS GLOVER (AGDE-1)

The CNO Pilot Program, funded by CHNAVMAT, for reduced bridge manning offered another means for evaluation of the collision avoidance concept. The program suggested the possibility that collision avoidance devices may have a direct impact on the more effective use of bridge manpower. Therefore, two more DIGIPLOTS, one of which was installed on the Atlantic Fleet auxiliary ship, USS DETROIT (AOE-4) and the other on a Pacific Fleet destroyer, USS ROARK (DE-1053) were procured. Additionally, a Sperry Collision Avoidance System (CAS) was installed aboard the Atlantic Fleet destroyer, USS W.S. SIMS (DE-1057)

Both formal and informal test operations were performed aboard GLOVER and ROARK between July 1972 and December 1973. The DETROIT operated its DIGIPLOT for about one year starting in November 1972, while the W.S. SIMS has continued to operate and test the Sperry CAS since the summer of 1973. All of these ships have deployed overseas with the devices and have had broad operating experience with them under the varying conditions usually experienced by Navy ships.

III. DESCRIPTION

In general, a collision avoidance device (CAD) is used in junction with basic ship's radar to improve understanding of the tactical situation with respect to radar targets. As an adjunct to the surface search radars installed aboard ship, CAD is designed to provide the data needed by ships

ABSTRACT

This report is a description and concept evaluation of the results of Fleet experience with two computer aided collision avoidance devices. The study was funded under the Chief of Naval Operations Pilot Program for Reduced Bridge Manning and the Navy Science Assistance Program.

During the period July 1972 to July 1974, four Atlantic and Pacific ships, including three 1052 Class Destroyer Escorts and one Auxiliary Service Ship, participated in the study. All of these ships were deployed overseas gaining broad operating experience with each device.

The results of analysis of at-sea test data and observations demonstrate that the advent of collision avoidance devices offers a new technological dimension for naval application. In particular, it is noted that this concept can enhance shipping safety, reduce the peacetime workload of the CIC and eliminate the need for having more than one radar repeater on the bridge.

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I. INTRODUCTION

The objective of this document is to provide a concept evaluation of the application of computer aided collision avoidance devices for use in the U.S. Navy. It is a treatise based on a comprehensive analysis of tests and observations made during fiscal years 1973 and 1974 aboard four U.S. Navy ships. In the conduct of the evaluation two different systems, which were available for testing in a Navy environment, were studied. This was done, not with the purpose of selecting specific equipment; but to provide conclusive documentation as to the relative naval worth of the collision avoidance concept.

II. BACKGROUND

With the widespread introduction of radar aboard ship, a new technological dimension was introduced into the collision avoidance equation. Techniques were developed that enabled the effective use of radar to evaluate and make decisions relative to threats of collision. These methods, using manual plotting and geometric computation, were comparatively slow and manpower intensive; however, they proved to be a vast improvement over relying on eyesight and judgement alone. This was especially true in fog or situations in which visibility was limited. In the Navy, as well as in the merchant fleet, various methods of calculating the data needed to determine the collision threat are employed. Most Navy ships determine this information by manual plotting means, both in CIC and on the bridge, using a true (North up) radar presentation. The merchant fleet, on the other hand, generally uses a head-up (relative) presentation on the bridge. In both cases, observation of contact bearing drift is a basis of determining danger.

During the latter half of the 1960's a series of computer aided devices for collision avoidance were developed by various manufacturers for use in the merchant marine industry. The common objectives in development of these devices were to provide the surface vessel with:

1. A more precise method of determining the potential danger of collision.

2. A recommended safe course to steer to avoid collision.

3. Concise information presented in such a way that it enhanced the timeliness of the maneuver decision.

It was found, however, that no one device provided all the desired features. As is expected between different models and manufacturers, various degrees of success were reported. These devices, however, generally provided substantial assistance in the shipboard collision avoidance function. It is this concept and the possibility of adaptation to U.S. Naval ships that stimulated investigation.

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personnel to allow for better judgements to be made witn regard to collision avoidance. This advantage is given by telling own ship where the targets are, what they are doing at the moment, where they will be at some future time (if on steady course and speed), and what will be the consequences of own ship maneuvers.

The devices discussed in this report use a general purpose computer in conjunction with the main ships service radars to display future target vectors and calculated data. It is recognized that in some instances an operator can obtain more accurate information about a target by manual plotting means rather than by a computer; however, it is the computer's capability for rapid calculations that make it desirable.

Among the many collision avoidance devices available are the Iotron DIGIPLOT and Sperry CAS, which are the subjects of evaluation in this report, and the following:

1. Nor Control DATA BRIDGE

2. MARCONI Predictor

3. GEC-AE1 A4 COMPACT

4. Marine Digital Systems COMAN

5. IBM System 7/MABS

None of the latter five devices have been tested for naval use, nor are any presently installed on board any U.S. Navy ship for evaluation. Main feature descriptions, obtained from the manufacturers of these particular devices, are shown in Appendix A. These summaries are intended to inform the reader as to the commercial availability of collision avoidance devices, not to bias opinion toward a particular system.

With the exception of the Iotron DIGIPLOT, IBM 7/MABS and MARCONI Predictor, collision avoidance devices require manual identification of the target to be tracked. After acquisition, the computer automatically searches the area where the target was first identified and then automatically tracks it, storing in its memory, range and bearing as a function of time. Using this information in conjunction with own ship course and speed data, the computer continually correlates data for the collision

avoidance equation. Generally, future vectors for the tracked targets are shown, and additionally, calculated information such as the closest point of approach (CPA), time to CPA, etc. are available for display.

The way the aforementioned information is presented varies between manufacturers. Certain of these devices are fully automatic, while others must have discrete manual inputs or queries by operator to provide required information. Some units will provide all of the required information on a single display while others will use an auxiliary tube or counters for additional alphanumeric data. Regardless of the method of target acquisition or display concept, the essence of the device is to determine the position of the target as a function of time taking into account own ship and target maneuvers for display of future vectors.

It should be noted that the COMPACT and COMAN devices are no longer in production and that the PREDICTOR can only be used with Marconi Radar. The most recent introduction to the commercial market is the IBM 7/MABS, which is currently undergoing preliminary examination by the U.S. Coast Guard. Considering these devices, the two produced in the United States which have the largest distribution are the Iotron DIGIPLOT and Sperry CAS. In Appendix B, a detailed description is compiled on the two devices that were tested in this concept study. Reading of this appendix will provide more detailed information before continuing to the evaluation summary section that follows.

IV. EVALUATION

In order to evaluate incorporation of a new collision avoidance concept into U.S. Navy doctrine, collision avoidance devices were installed on operational ships in order that:

1. Personal experience by operational personnel could be obtained.

2. Maintainability and reliability in a realistic environment could be examined.

3. Applications to various tactical or navigational situations could be observed.

The method followed in this evaluation consisted of a threefold approach:

1. First hand observation by Ship's company personnel over a period of time.

2. Observation by Destroyer Development Group test team members.

3. Technical evaluation of Iotron DIGIPLOT by the Navy Electronic Center, San Diego (NELC).

The evaluation centered mainly on the conceptual use of collision avoidance devices rather than on the selection of individual equipment. On this basis, heavy weight was applied in the analysis of observations made by shipboard personnel instead of using a quantitative approach.

In Appendix C, the Iotron DIGIPLOT and Sperry CAS have been evaluated individually on a limited technical scale. The evaluation which follows compares and contrasts the two devices in general terms. For more detailed technical information, refer to Appendix C. Each device was evaluated in the following general areas:

1. Capability
2. Confidence
3. Maintainability
4. Operability

Both the Sperry CAS and the Iotron DIGIPLOT were analyzed in a variety of actual operational conditions. This technique provided data on collision avoidance, with respect to the four terms above.

At the request of COMDESDEVGRU, funds were provided to expand the collision avoidance study by means of a NELC technical report. However, funds were not available to meet a similar request for an evaluation of the Sperry CAS.

The collision avoidance devices that are considered in this report are passive in nature; there are no communications links with other vessels, nor does the system exercise direct control over own vessel. As in any system where command and control decisions are highly critical, ultimate action must be left to the human operator. Furthermore, any computer aided device - of necessity - must not degrade the operational capability of own ship by providing erroneous information or by creating confusion which would lead to a faulty maneuver decision.

Each CAD was evaluated with these considerations in mind.

CAPABILITY:

The capability of these devices to perform the collision avoidance function, as indicated in Appendix C is limited. Observations and interviews conducted during the evaluation period indicated the console displays of each device could at least support or aid collision avoidance decisions. Further, it was shown that an operator must not have anything less than the information displayed by the SPS-10 radar. Raw video display, along with the computer generated symbology, was the most desired manner of console presentation; for this provided no less than the display of the SPA-4 or SPA-25. This observation is readily understood, since with the "all automatic" DIGIPLOT, a most undesirable characteristic of dropping targets or targets not being displayed by its computer selected video occurred with objectionable frequency.

Sperry CAS appeared to provide a more effective technique with respect to lost tracks. First, a target track loss alarm feature was provided. Second, the system allowed for search of lost targets with a "real time" presentation identical to the SPS-10. With this type of display, at least an effort can be directed toward studying and searching for the lost contact without having to shuffle between the collision avoidance console and radar repeaters as had to be done with the DIGIPLOT. With the DIGIPLOT, all presentation is lost when the computer fails; but, in the case of the Sperry CAS, raw video continues to be displayed. Augmentation of this type of device with a plotting head, similar to the conventional type used with repeaters, would allow manual plotting to be resumed routinely and with little delay if a system failure alarm was installed.

Finally, manual or automatic acquisition has benefits. Where 100% automatic acquisition existed, flexibility and reliability of the device became a problem. Where 100% manual acquisition existed, operators were encumbered by attempting to keep up with all targets. A conclusion may be derived when considering some of the most useful characteristics of each device. It follows, that an effective system must be characterized by selectivity in operating on manual or automatic acquisition. This allows for the automatic mode to acquire contacts faster, and the manual mode to give the operator the opportunity to choose targets that warrant investigation or targets that, for some unknown reason, have not been acquired by the system within its tracking range.

Digital data readout is displayed on the console by DIGIPLOT as to the range and bearing, course and speed, and CPA distance and TIME-TO-CPA for any target or own ship. As discussed in Appendix B, the data is called up by a manual selection of individual targets. On the other hand, the Sperry CAS, for Navy purposes, was installed with an auxiliary alphanumeric display which presents the same type of information on a cathode ray tube. As with the DIGIPLOT only one target could be investigated at a time, but unlike the DIGIPLOT'S readout, which is updated every scan, the alphanumeric display of the Sperry CAS is updated on command only.

In comparison, both systems provide the necessary computation of variables that establish the collision risk picture for the OOD. Reviewing the figures that show methods of display (Figures B-3 and B-6 of Appendix B), it can be seen that a combination of the DIGIPLOT and the Sperry CAS's methods of providing digital data on contacts relates well with the conventional grease pencil charting on the bridge. The fact that the information called up on a particular target is automatically updated every scan is a "plus" in DIGIPLOT's operations contrary to the Sperry CAS. On the other hand, an auxiliary digital display, like Sperry's, that will present updated target data both automatically (or on call) would be effective in eliminating the need for recording similar data on the bridge's surface contact status board.

CONFIDENCE:

The likelihood of acceptance of, and confidence in, the DIGIPLOT or Sperry CAS was limited at the outset, since they were in competition with the current and relatively effective methods of avoiding collision. The experience with each device prior to testing and evaluation was considered adequate in light of this evaluation's limited objectives. A basic consideration in this analysis is that we know the bridge has a certain level of confidence in the CIC's ability to interface with bridge operations and the bridge's ability to see hazards, comprehend danger and to make appropriate maneuver decisions. Unless complete automation could be achieved with near 100% reliability, a degree of acceptance of certain limitations must occur in the man-machine interface (as is the case with the conventional manner of operating).

In the case of the Iotron DIGIPLOT, OOD's developed a negative attitude. These feelings were precipitated by several notable drawbacks in the system. The fact that contacts were dropped, or not picked up often enough, deterred any high level of confidence in the device. In terms of design, this relates directly to the computer generated

video; it simply did not depict targets that could be readily seen on SPA-4 or SPA-25 repeaters on the bridge. These adverse feelings were further reinforced when the system would interpret heavy weather or high sea states incorrectly and show these conditions in the same manner as it would land masses. For these reasons, the CIC was still required to report on surface contacts as a matter of routine -- especially during periods of high density traffic. The device was used more often as a verification aid, rather than a decision aid. Although this reaction can be expected during the learning phase in the introduction of any new equipment, this lack of confidence cannot be attributed to the learning process during the year in which the Navy experience was gained.

The degree of success achieved by the Sperry CAS in gaining confidence in its operations was marked, in comparison to the DIGIPLOT. There are several reasons why OOD's reported reasonable confidence in the use of the Sperry CAS for collision avoidance support. First, the display of raw video on the system allowed for human evaluation rather than having to rely solely on processed data. OOD's were confident that they could correlate computer generated symbology superimposed on raw video expeditiously, however, this confidence was reduced during high density periods when computer generated symbology cluttered the console display. This particular situation can be alleviated somewhat by terminating tracking with manual release of targets least threatening to own ship. Second, the confidence level was bolstered even further because there was an alarm that would warn the OOD of the fact that a target track had been lost.

MAINTAINABILITY:

The nature and difficulty of maintenance problems were not documented nor fully analyzed within the scope of this concept evaluation. It must be considered that this equipment was not procured with the intent of being made rugged for naval use, nor was it designed to specifications in which maintainability by on-board personnel was a requirement. It is expected that any procurement for general use would be designed to fulfill such requirements.

Both the Iotron DIGIPLOT and Sperry CAS use circuit cards functionally divided to aid in trouble shooting. In each case, other difficulties were experienced to such a degree that factory representatives were required to correct the problems. As is noted for each device in Appendix C, there were certain problems associated with installation

in the Naval shipboard environment. In the case of DIGIPLOT, it was difficulty in interfacing with the AN/SPS-10 (more detailed description on Page C-3); with the Sperry CAS, it was interference from the AN/SPS-40 - Air Search radar.

Through the course of the evaluation, it was expected that only a limited degree of maintenance would be performed by Navy technicians. These technicians were given a short orientation or factory training program in maintenance problems which could only be corrected by factory engineers. Although each system experienced a high degree of maintenance down time, none of the failures were sufficiently acute to be considered uncorrectable by well trained and equipped shipboard technicians.

OPERABILITY:

The operation of the collision avoidance devices examined in this evaluation was simple to understand with a minimum of orientation or training. The DIGIPLOT, however, presented a problem in that the OOD had to examine two physically separated displays to obtain the necessary information for his decision. There were favorable comments as to the size of both displays (16" diameter), but each had to be shaded during day operations. Additionally, the characters (3/16") on the Sperry CAS auxiliary CRT were hard to read, however, this was not considered a major problem area.

V. CONCLUSIONS

Each device examined herein demonstrated several limitations specifically related to its design. Although the reliability and operability of the equipment was questionable at times, collision avoidance devices have usefulness in a Navy environment. Some observations which derive from an optimal use of computerized collision avoidance devices are the following:

1. Better collision threat analysis by OOD's will result by allowing him to observe the whole situation (present and future) and to make a decision that will permit timely ship evasive maneuvers, if required.

2. Combat Information Center (CIC) manning requirements for manual tracking and plotting on surface contacts can be reduced during peacetime operations. (Essential training requirements are acknowledged.

3. The need for having a second repeater for use by the OOD may be eliminated by the use of a collision avoidance device that has a plotting head.

VI. RECOMMENDATIONS

The U.S. Navy should identify and investigate for possible procurement, a collision avoidance device meeting military specifications which has as a minimum the following features: (Note - In some instances a recommendation is followed by an explanation of why it is desirable.)

1. Raw radar video and computer generated information superimposed on a single 16" (minimum) display. The raw video should be comparable to the ship's service radars with regard to definition and the ability to indicate targets.

2. Controls for the device and the electronic interfaces with the radar that do not affect the service radar displays nor their performance.

3. A heading line (removable on demand) should be shown and the system should have a bearing ring around the PPI.

4. Range rings and a bearing cursor and strobe to mark bearing and range of contacts (with digital readout).

5. It must be possible to remove all (or part) of the synthetic information from the display without losing the information contained within the system.

> The ability to remove synthetic information from the screen is considered necessary in order to be able to visualize any targets which are hidden and to minimize confusion caused by too much information.

6. Relative or True Motion Vectors controllable in time.

> By having time controlled vectors, the operator can reduce the length of the lines displayed on the screen. This also helps in seeing targets and minimizing clutter on the screen. Additionally, controlling the length of vectors permits the separation of overlapping vectors (when targets are on the same track). This helps in eliminating

ambiguity regarding vector direction. Indicating the origin of the vector helps in eliminating ambiguity regarding vector direction. It also identifies which target has been entered into the system in the event no vectors are shown, so that a target is not entered into the system twice.

7. Display must indicate last known position of a target which has been lost from the system.

8. A plotting head should be installed for back-up capability.

9. Daylight viewing should be possible without the use of a hood or curtain.

10. Variable Collision Danger input. (Minimum CPA data)

Danger criteria should be variable as situations change, depending on the type ship and area of operation.

11. Manual identification of targets, indicating to the computer which targets to track or remove from track.

12. Automatic acquisition of targets in order to compensate for possible operator inattention or overload. The device should be capable of tracking more targets in this mode than when in the manual mode.

Automatic acquisition implies the machine is making correct judgements regarding differentiation between clutter, real targets and land, and which targets are dangerous or non-dangerous. While automatic acquisition can substantially reduce the work load, it should be capable of being overridden at any time in the event the device becomes saturated by extraneous targets or does not pick up a desired target.

13. The device must be capable of resolving (tracking) two targets individually that can be resolved visually on a standard radar display (e.g. tug and tow).

14. Changing range scales or display mode must not cause loss of track of any target entered into the device.

15. Auxiliary display that will provide continuously up-dated information on the six most dangerous contacts. The listing should be as follows:

a. Contact designation (three digit numeric)
b. Range and bearing
c. Bearing and range to CPA
d. Contact course and speed
e. Time of CPA

16. Audio Alarms that will indicate:

a. Danger of collision
b. Dropped target
c. Device failure

APPENDIX A

Characteristics of Collision Avoidance Devices

These design details do not include changes or modifications made subsequent to the evaluation. The following table was constructed on information obtained from various industrial sources. Note: where specific data is unknown, it is annotated NA (Not Available).

Devices Characteristics	Databridge	Predictor	Sperry CAS	Compact	Digiplot	Coman	IBM 7/MABS
Console PPI Diameter	NA	16"	16"	16"	16"	16"	16"
Computer Operated	Yes	NO (Uses video tape recorder	Yes	Yes	Yes	Yes	Yes
Raw Video Displayed	Yes	Yes	Yes	Yes	No	Yes	Yes
Relative/ True Motion Video Selectivity	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Superposition radar & vectors	Yes	Yes (Past track history only)	Yes	Yes	No (Dotted outline of land mass)	Yes	Yes
Variable Vector Control	Yes (30 & 15 min.)	No	No	Yes	Yes	Yes	Yes
Method of TGT Acquisition	Man	Auto (no override)	Man	Man	Auto (no override)	Man	Man/ Auto
Maximum tracking Range	24 NM	24 NM	12 NM	24 NM	17 NM	24 NM	16.5 NM
Tracking Capability	15	All	40	12	40	28	21

Devices Characteristics	Databridge	Predictor	Sperry CAS	Compact	Digiplot	Coman	IBM 7/MABS
Listing of Target Data	Yes (Digital Display on Console)	No	Yes (Auxiliary Display)	No	Yes	Yes(separate CRT listing)	Yes (separate CRT listing)
Automatic Listing of Tabular TGT information	No	No	No	No	No	Yes	Yes
Trial Maneuver Capability	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Dynamic Characteristics included in trial maneuver	No	No	No	No	Yes	Yes	NA
Lost Track Alarm	NA	NA	Yes	NA	No	NA	NA
Collision Threat Alarm	NA	NA	Yes	NA	Yes	NA	Yes
System Failure Alarm	NA	NA	No	NA	Yes	NA	Yes

APPENDIX B

DESCRIPTION OF COLLISION AVOIDANCE DEVICES

ABOARD U.S. NAVY SHIPS

1. IOTRON DIGIPLOT

DESCRIPTION:

The Iotron DIGIPLOT is a collision avoidance device that automatically processes signals from the ship's surface search radar, gyro compass and ship's log. (See Functional Block Diagram - Figure B-1) Subsequent computations relative to ship's dynamics are made by the central processor of the device providing information for separate numerical and pictorial displays of collision risks. The capacity of this particular system for tracking and display is 40 surface targets within a maximum range of 17 NM. Where there are more than 40 targets within 16 NM, the selection of targets for tracking and display is based on their present range and whether they are opening or closing in range. Within a 1 NM range, all targets up to 40, whether opening or closing, are tracked and displayed.

The pictorial displays provided to the ship's watch officer include detailed, continuous up-to-date information concerning the true or relative motions of other ships; outputs are updated every scan. Besides providing collision prevention data, the system displays the closest edge of land masses to render own ship navigational assistance to prevent grounding in close waters. In these waters, range and bearing values of a known fixed point can be continuously displayed on the digital data readout to provide radar data for direct plotting on a navigational chart. By selecting a known fixed-point as a target, the values displayed for course and speed establish inputs for the "SET" and "DRIFT" controls. This setting allows for courses and speeds of all targets to be corrected to values being made good over the ground.

The symbology used by DIGIPLOT, displays targets as a small circle and land masses as a dotted outline of the nearest land edge. Examples of this symbology are in Figure B-2. A velocity vector is attached to the target circle to provide maneuver information in true or relative motion.

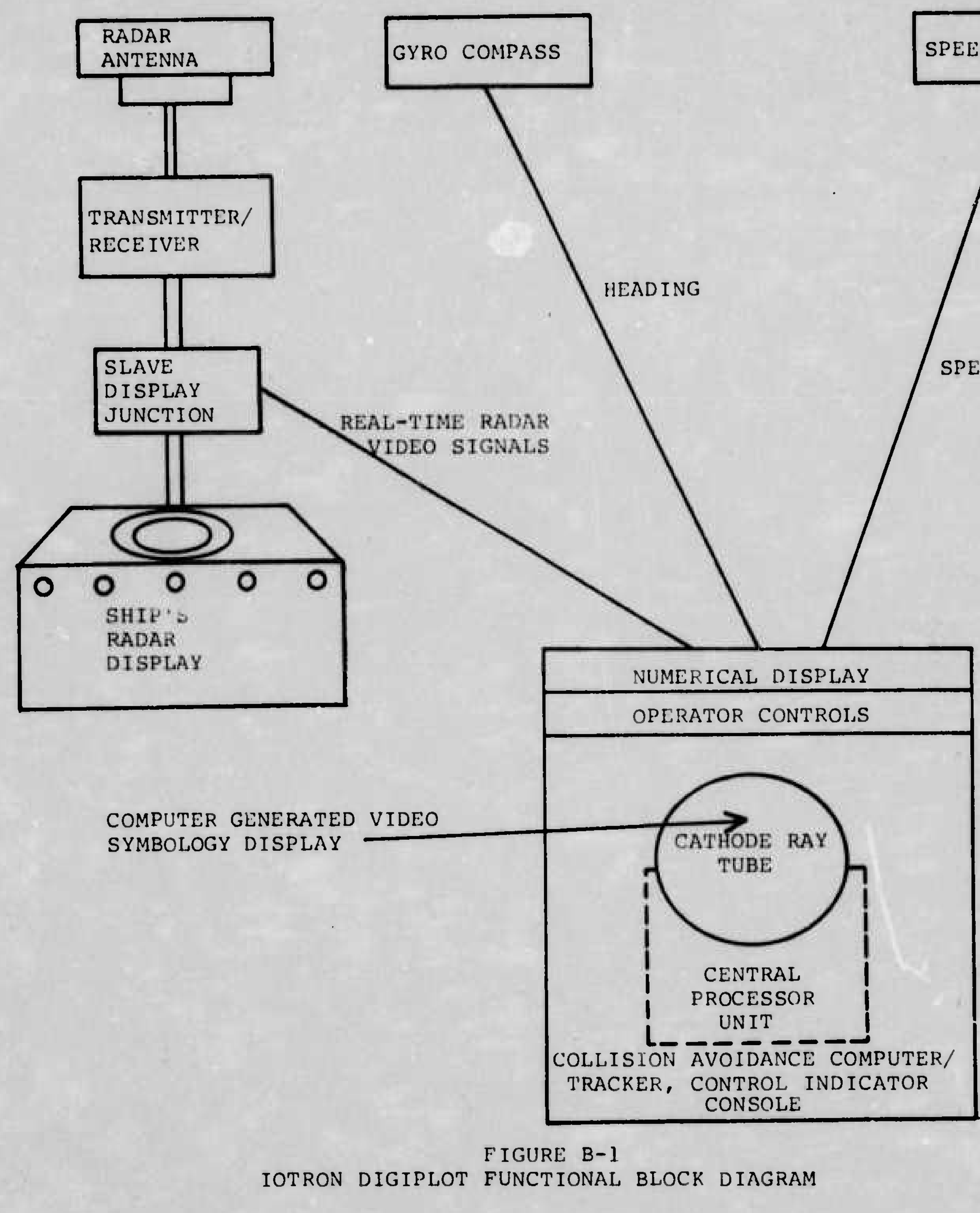

FIGURE B-1
IOTRON DIGIPLOT FUNCTIONAL BLOCK DIAGRAM

The vector length is continuously adjustable in terms of time increments (0-69 minutes) and is selected for predicting a target's future position. When data correlating a collision threat is detected by the device, a visual and audio alarm are triggered. The alarm threshold is set for any desired combination of CPA distance (0-7.9 NM in 0.1 NM increments) and Time-to-CPA (0-39 minutes in 1 minute increments) by own ship. The visual alarm is indicated by a brighter than normal target circle and vector. The audio alarm, a BUZZER, may be silenced at the operator's discretion; but it will be resounded when a subsequent alarming collision situation occurs.

DIGIPLOT'S PPI presentation may be either north up or ship's head-up. This capability allows comparison between the device's display on the cathode ray tube and the PPI of the surface search radar. The display will not correspond, however; because radar video signals fed from the SPS-10 will be detected by the video processor and computer generated symbology will be used to depict the real time situation. The processor unit identifies echoes and separates "small" from "extended" targets. Targets whose "equivalent echoing area" are greater than the largest vessel's echoes are classified as extended. The range and bearings of the closest edge of these extended targets (coastlines) are processed for display on the cathode ray tube (CRT). These echoes are represented by a series of dots 2 degrees apart outlining the nearest edge while small targets are further evaluated in the central processor as candidates to be tracked. The DIGIPLOT display may be switched to show 3, 6, 12, and 24 NM range scales. These functions are accomplished independent of the settings on SPS-10 Radar.

Digital Data Readout is provided on a twin numerical display of range and bearing, course and speed, or CPA distance and Time-to-CPA for any target selected that is presented on the CRT. (See Figure B-3) The desired data pair is obtained by manual selection and is updated every radar scan. The desired target is identified by use of a target selection function on the console. Note: Own ship's course and speed may also be selected for presentation. Besides monitoring and displaying information on threatening targets to determine collision risk, the DIGIPLOT has a trial maneuver function which allows for projection of results of own ship and target ship maneuver. The trial maneuver assumes all targets will maintain course and speed; and own ship's dynamic characteristics, which are entered at the time of installation,

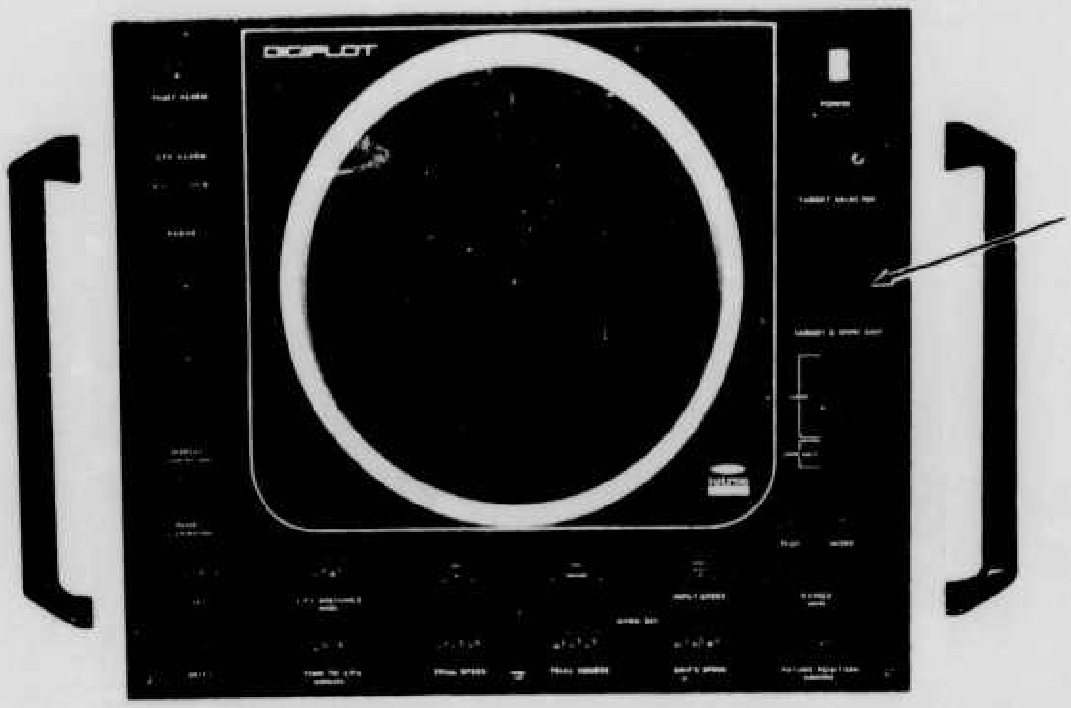

FIGURE B-3

DIGIPLOT

DIGITAL DATA READOUT

are taken into account for the predicted effect of own ship maneuver. The progress of the prediction is displayed in its entirety at a speed of 30 times "real time". During the trial maneuver, DIGIPLOT continues to monitor the actual situation. Should dangerous collision risk occur during this function, previously mentioned alarms will be triggered so that the operator may instantly return to normal operations.

2. SPERRY COLLISION AVOIDANCE SYSTEM (SCAS)

DESCRIPTION:

The Sperry CAS processes signals from the ship's surface search radar, gyro compass and ship's speed log to analyze and display collision risk data. The device utilizes a general purpose digital computer which has a memory expansion capability. The basic system has the capability for automatic radar fixing, display of shoal data, ground speed and is additionally capable of automatic fixing, using navigational aids, e.g. satellite, Decca, Omega, or Loran navigation receivers. The basic system has the capability of automatically tracking 40 surface contacts that have been manually selected from the console display. Targets are selected from a raw "real time" video display which is identical to the SPS-10's radar PPI. Even should the computer fail, video will continue to be displayed. A functional diagram is located at Figure B-4 describing Sperry CAS operations.

The Sperry concept of collision avoidance is based upon determining and displaying the points of possible collision (PPC) of target ships and an associated predicted area of danger (PAD). The predicted area of danger is an elliptical or circular shaped symbol which encloses all PPC's within the watch officer's selected minimum safe passing distance (CPA Distance). It lies along the target ship's projected track line. The end of the line is the point at which one would expect to hit the target. To avoid a collision, own ship must avoid the end of all vectors. By avoiding the areas of danger for each target, own ship will stay out of danger, passing clear by the minimum safe passing distance selected by the watch officer. The CPA Distance is selected by the watch officer to specify acceptable safe passing distance. The selections allowed are 0, 1/8, 1/2, 1, and 2 NM.

After a target is manually designated by "tagging", using a joystick control and triggering the manually activated acquisition switch; radar data for the target at a range

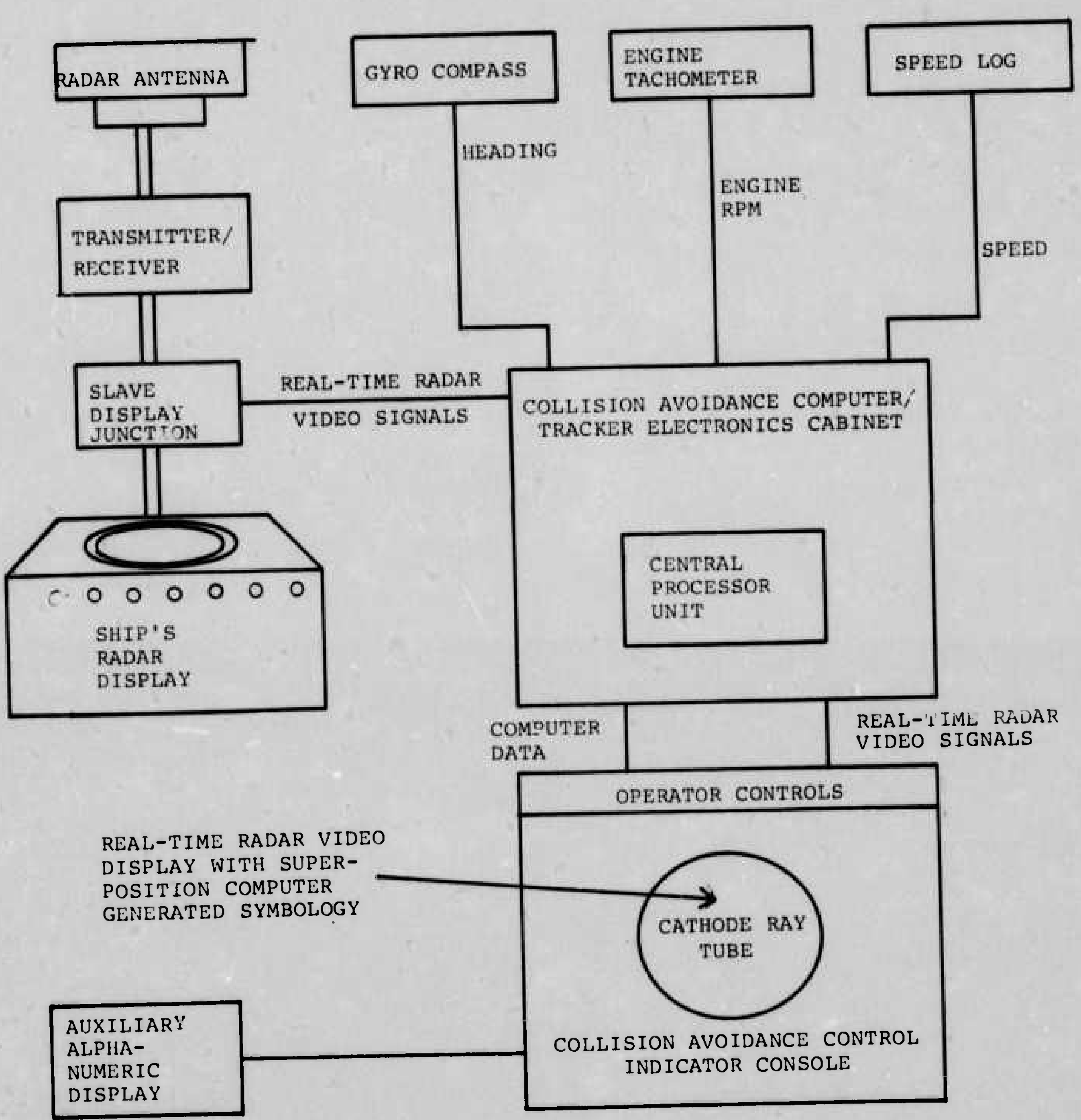

FIGURE B-4
SPERRY COLLISION AVOIDANCE SYSTEM FUNCTIONAL BLOCK DIAGRAM

greater than 250 yards and less than 12 NM will be accepted by the system for automatic tracking. After acquiring a target, a vector that represents the target's true course and the distance it will run in five minutes is displayed. After 20 radar scans, a projected track line is drawn on the display from the target's present position to the PPC. The direction of the projected track line is the heading of the target with respect to own ship's heading.

A magnetic cassette tape-reader is used to feed programs into the computer and for diagnostic testing. In order to evaluate and analyze own ship's need to maneuver and results of a proposed maneuver, two electronic cursors are used. The heading Cursor as displayed at Figure B-5 denotes own ship's heading at 5 minute intervals. Upon observation of a heading that intercepts or comes too close to a PAD, a prediction mode using a Bearing Cursor is selected to show the results of a proposed new course of own ship or to determine target bearing. Note: The system will continue to be up-dated while in the prediction mode, and alarms for the real situation will remain effective. The electronic bearing cursor is represented by a dotted segmented line.

There are four basic audible and visual alarms designed in the Sperry System. A MASTER CAUTION LIGHT illuminates to indicate an alarming situation exists. It will remain illuminated until the problem is clear. Triggering a flashing MASTER CAUTION, the COLLISION WARNING display indicator will illuminate if a tracked target will pass within one mile in less than 20 minutes. Whenever a tracked target will pass within a 1/2 NM in less than five minutes, the MASTER CAUTION and a visual status display indicator are illuminated and a continuous "BUZZER" alarm sounds. The audible alarm can be acknowledged and silenced but the MASTER CAUTION will not be extinguished until the problem is cleared. If a tracked target is not getting radar hits on 5 of the gated scans(20), the target track is then considered marginal and the LOST TARGET RETURN warning will illuminate and the target PAD will flash. It should be noted that if no target return is received during 10 scans, the target is considered lost and is automatically dropped.

The Alphanumeric Data Display Terminal provides digital information on target course, speed, CPA, and time-to-CPA. (See Figure B-6) An example of the display provided on the 16" cathode ray tube where computer generated synthetic data is superimposed upon the raw data is at Figure B-5. The range scales that can be selected for display are 1-1/2, 3, 6, 12, or 24 NM.

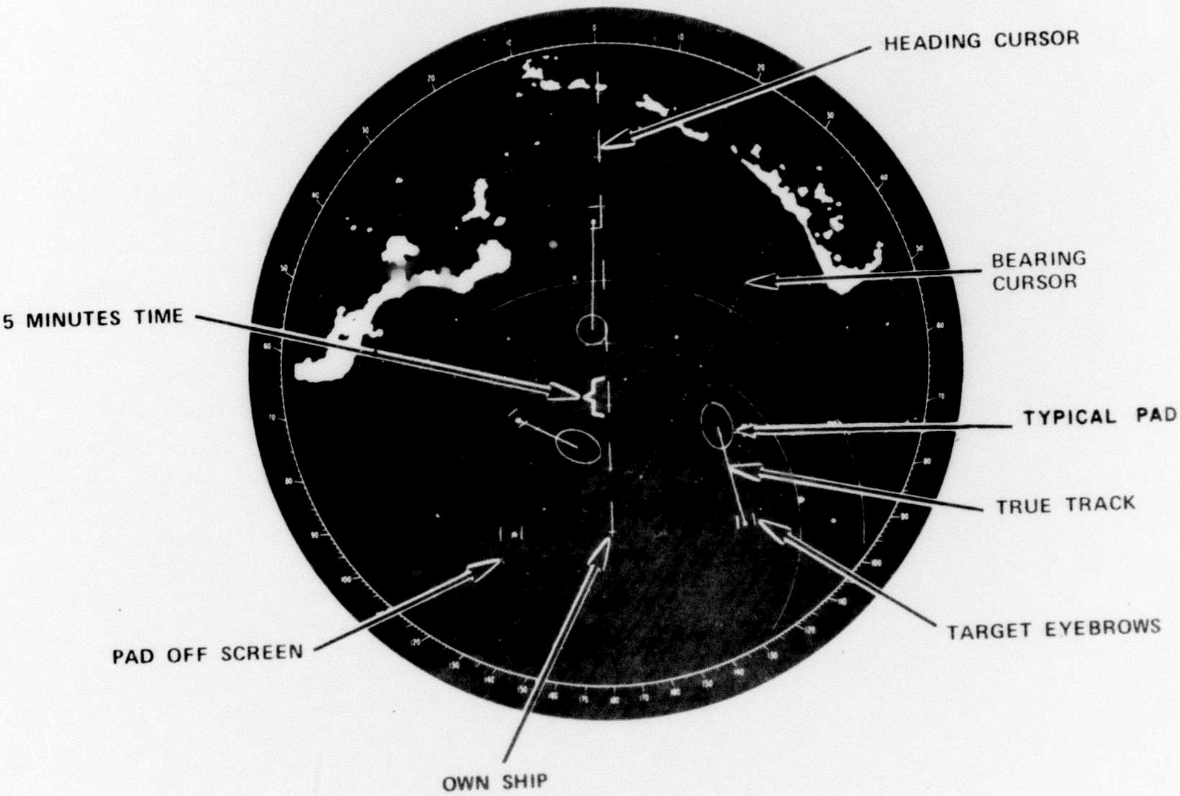

FIGURE B-5

SPERRY COLLISION AVOIDANCE SYSTEM

SYMBOLOGY

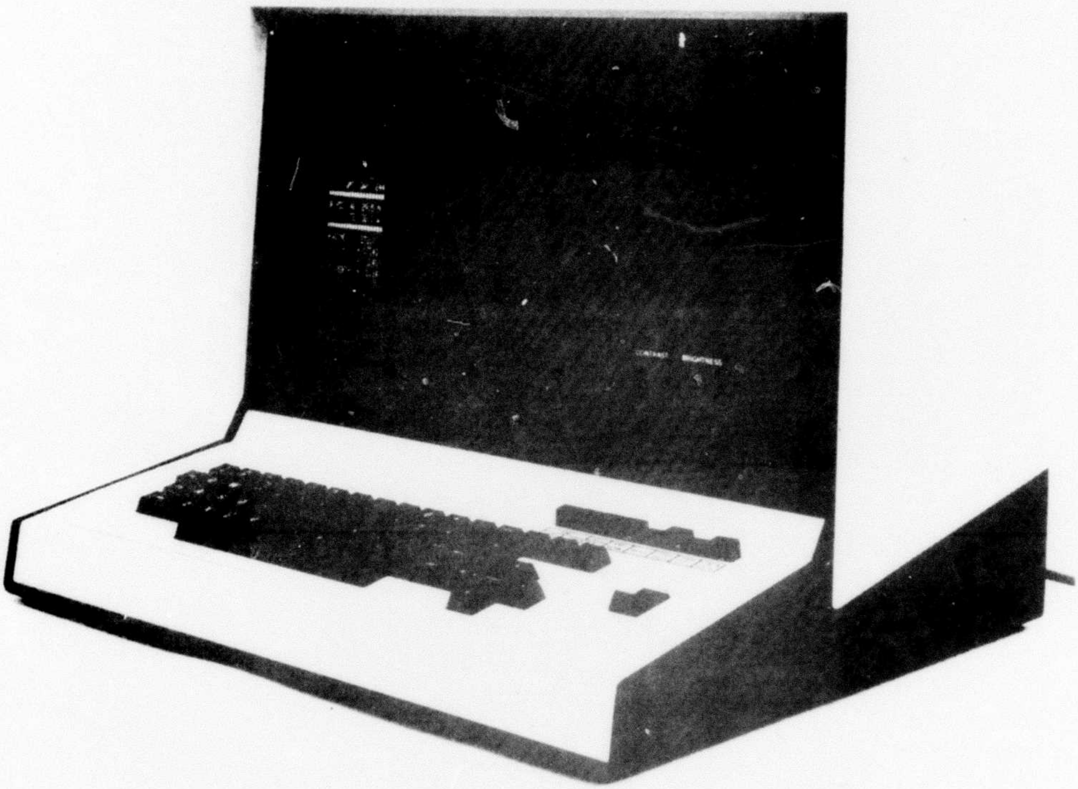

FIGURE B-6

SPERRY COLLISION AVOIDANCE SYSTEM

DATA DISPLAY PANEL

In the SCAS's navigational function, Dead Reckoning (DR) computations are performed automatically in the computer using own ship's heading and speed. This navigation loop can be used for open ocean travel and for coastal piloting. This dead reckoning program is initiated at the time of departure. The latitude and longitude of the points of departure are entered in the computer and are displayed periodically. While underway, the computer continuously integrates the speed good to determine the ship's present latitude and longitude.

In coastal piloting, updating the plot is required more frequently to ensure against grounding or contact with other navigational hazards. Data on navigational landmarks are prestored on tape which are inserted into the computer before the voyage. When in radar range of a landmark, the landmark's position is shown on the collision avoidance display. Alignment of the radar and computed data on the landmark is required to be assured of own ship's position with respect to the bottom. The navigation/piloting function is used once the chart is aligned by acquiring the desired references. The position of own ship is computed continuously using range and bearing to one or more navigational references.

APPENDIX C

EVALUATION OF COLLISION AVOIDANCE DEVICES ABOARD U.S. NAVY SHIPS

1. IOTRON DIGIPLOT

GENERAL:

As discussed, DIGIPLOT was installed on the USS GLOVER (AGDE-1), USS ROARK (DE-1053) and the USS DETROIT (AOE-1). Each ship compiled one or more years experience with the device. DESDEVGRU observers embarked on all three ships for periods up to ten at-sea days and NELC conducted their technical evaluation for periods of about one week at-sea time. The observations of all personnel involved, including the ships personnel, as well as project personnel, are examined below.

CAPABILITY:

Observations taken from the test ships show that the OOD frequently used the DIGIPLOT in lieu of calculating course, speed, and CPA; but the system was not relied upon in every case. In general, OOD's thought that their capabilities were enhanced; but few would recommend eliminating the CIC input on surface contacts. Statements were made that the DIGIPLOT did give needed information, however, the fact that the system would drop targets during periods of high-sea state was a nuisance. NELC Technical Note 2370 reported that the reacquiring of dropped targets was difficult; because the computer was not designed to maintain track history and the contact would not fulfill the persistency requirements for initiation of a track. The minimum time for target acquisition and display by DIGIPLOT when connected to the SPS-10 radar is 20 seconds. This is a requirement for five good radar responses, however, acquisition time could even be extended up to one or two minutes depending on the number and quality of radar responses. Additionally, intense weather can cause DIGIPLOT to dot out an area as if it were a land mass. Further, confusion may occur with high sea states.

The DIGIPLOT's capability for automatically acquiring the closest 200 target echoes and selecting the 40 most threatening surface targets to track was relatively in-

flexible. Second, time taken to shuttle between the bridge radar repeater and the DIGIPLOT to obtain proper assessment of contact characteristics merely added to the strain of the maneuver decision making process. In each case raw video input and manual acquisition would bolster the system's ability to perform its collision avoidance function. In its present status, the device does not provide sufficient information on its PPI to permit positive target identification and coastline recognition; a radar repeater still must be used for target correlation. This occurs because of the confusing anomalies, presented by the DIGIPLOT, that have to be sorted out on bridge repeaters. Some examples are that some land echoes may be tracked and displayed as targets; targets that produce weak radar echoes may not be presented; and weather may be tracked and displayed with false vectors.

DIGIPLOT's digital data readout was found to provide essential target and own ship data. Display of this information, however, is presented only in pairs on the console. To call up target range and bearing, or course and speed, or CPA and TIME-TO-CPA or own ship course and speed; a separate selector push button must be chosen to view the desired ordered pair. This can be done only after a contact has been designated for investigation with a target selector function. Note: This function has no bearing on the selection of targets to be tracked, and only one target at a time can be investigated. For increasing numbers of targets, this function does not provide a substantial assist to OOD's, as a status board with current data would. First, the status board would have an identifier on the target; and second, all the needed target information would be listed so that it could be evaluated at a glance.

These capability limitations fail one of the basic criteria used in this evaluation, in that it becomes mandatory for the OOD to correlate the pictorial and numerical data of at least two displays in order to ensure completeness of information. The use of a device that displays less complete information, with regard to raw video, than the SPS-10's ability to input, does not allow opportunity for the device to enhance the decision making process.

CONFIDENCE:

Throughout the period of utilization of the DIGIPLOT, OOD's did not develop confidence in its DIGIPLOT's intended collision avoidance function. Contacts were dropped without warning, or often not picked up. This caused much concern as to the system's "Safety Oriented Purpose". The conven-

tional means of providing collision avoidance data were neither enhanced nor eliminated by the DIGIPLOT. As a matter of routine, the CIC was still required to report on surface contacts and OODs used the DIGIPLOT as an aid.

One characteristic which increased the confidence of OOD's was that DIGIPLOT would render accurate collision avoidance digital data on contacts it was tracking. Another confidence improving function was that the device had an equipment Fault Alarm that warned of system failures. The overall assessment of the DIGIPLOT, however, was that it did not provide the quality of information intended by its designers.

MAINTAINABILITY:

Digital circuits are utilized in the Iotron DIGIPLOT Central Processor for reliability. These large printed circuit boards involve minimum connections and are functionally divided to aid in fault finding. These circuit boards are easily removable allowing easy maintenance using the repair-by-replacement technique.

The experience with this equipment aboard ship showed that it could be maintained on occasion by an electronic technician using the replacement circuit boards provided by the contractor. Due to an inordinate amount of down time, a factory field engineer had to be dispatched by the manufacturers to meet ships in port and provide repairs during experimentation. It must be considered, however, that this equipment was not militarized nor was it built to specifications in which maintainability by in house personnel was a requirement. It is expected that any procurement for general use would fulfill such requirements, through design changes.

NELC reported that there was a problem with interface of the SPS-10 and the DIGIPLOT when selection of a different pulse mode was made. The fact that the SPS-10 can operate in a Wide Band Short Pulse (WSP) Mode or a Narrow Band Long Pulse (NLP) Mode gives it a capability not similar to any commercial radar. The DIGIPLOT was designed for use on merchant vessels with commercial S and X Band Radars. The SPS-10 operates in the C Band and with a peak power difference of its 285 kw vs 25 to 50 kw for commercial radars is the most significant factor to the DIGIPLOT. The resulting increased received target strength vs range and additional sensitivity to sea and weather clutter, is interpreted incorrectly by the DIGIPLOT. In the worst case, this sensitivity in heavy clouds and rain areas causes DIGIPLOT to determine them to be many point targets having same course and speed, or, if the weather is intense it will dot the area similar to land.

OPERABILITY:

The operation of the equipment was considered simple enough to be quickly understood by any OOD. Among the more favorable comments were those in reference to the size of the display and the train course indicators. The large screen (16" diameter) of DIGIPLOT made it easy to read in both day and night conditions. A sun shield had to be built and installed in order that DIGIPLOT could be readable when in direct sunlight, otherwise no difficulties were encountered in the actual operation of the equipment.

2. SPERRY COLLISION AVOIDANCE SYSTEM (SCAS)

GENERAL:

The Sperry CAS was installed on the USS W.S. SIMS (DE-1079) in the late spring of 1973. This particular ship tested the system for one year. During this time, SIMS deployed to Northern Europe and the Mediterranean areas as well as operating off the continental Atlantic Coast. A Destroyer Development Group representative observed the equipment in operation at sea for one week. During this period, SIMS transited the English Channel. This provided an opportunity to make observations during conditions which would tax the display and analysis capability of a device of this type to its fullest. Sperry's optional auxiliary CRT data terminal was installed to provide tabular readout on course, speed, CPA, etc. on selected targets. The following is an analysis of data and observations made.

CAPABILITY:

Based on the experience of the OODs of the USS W.S. SIMS, the CAS is considered a useful device in tracking and evaluating surface contacts. OODs reported that they can acquire and keep track of up to ten contacts at a time without loss in performance of their other duties. The presentation of real time CPA data on the auxiliary readout is considered an improvement over manual methods in making timely decisions with regard to collision avoidance. More accurate information is available for the OOD's use more rapidly than by previous methods. The inability of the equipment to automatically acquire targets (or to have an automatic acquisition option) was cited as a drawback for this particular equipment, in that the OOD had to continuously or frequently (depending on the tactical situation) refer to the equipment to insure that contacts were not overlooked. The OODs would prefer automatic acquisition on a manual-automatic acquisition option basis for at least ten contacts.

On the other hand, the lost contact alarm was considered a very important feature in keeping the OOD informed of his situation. As a result of installation of the CAS, SIMS was able to dispense with the CIC watch during independent transits.

During periods of high density, the large amount of synthetic data (PAD's, Vectors, etc.) available tends to confuse the picture. At such times, the need for a CIC watch is quite evident, in order to sort out and clarify the surface picture. During such situations, the CRT data terminal was extremely useful to the OOD, however, in its present configuration, the lines are too small to be easily read and the amount of information (including the number of decimal places) tends to confuse the user. (The OODs did not consider the Navigation Mode useful in that it did not perform properly, tended to clutter, and led to additional saturation of the presentation.)

CONFIDENCE:

The OODs reported that they had reasonable confidence in the use of Sperry CAS for collision avoidance support. The lost contact alarm was an important factor in instilling this confidence. Adding to this confidence was the fact that raw video was displayed for assessment. This presentation allowed for the OOD's personal evaluation of the collision risk situation rather than having a device that forced him to depend entirely on processed data. OODs felt they were correlating processed information with raw data expeditiously and that their decisions were more rapid in the "real time" situation. During high density periods, however, the confidence of the OODs falls off sharply, since they are too busy maintaining visual surveillance and evaluation of the situation, to apply the necessary time to properly use the CAS. Also, since the CAS does not have a means of discriminating between contacts, information processed on own forces tends to clutter the situation to a larger degree than would ordinarily be experienced.

Other shortcomings which reduced confidence in the SCAS include: (1) No means are provided for showing the alfanumeric designation of the contacts on the main presentation. (2) When two contacts are in close proximity, one PAD is lost. (3) During saturation periods, the number of PAD's on the console PPI degrade collision avoidance decision making rather than enhance it.

MAINTAINABILITY:

The CAS had a history of software and hardware problems during the first six months of operation aboard SIMS. These

were corrected by Sperry representatives, who also trained ship technicians in minor maintenance of the equipment.

The major maintenance or repair problem remaining involves loading of the tapes for the Navigational input. This has been an acute problem throughout the Navy experience with the equipment. Another problem area involves interference from the AN/SPS-40 Air Search radar which causes noise within the equipment. This may be partially due to the placement of Computer/Tracker Electronics Cabinet, which is mounted in the fire control room above the pilot house (just below the SPS-40).

Printed circuit cards are utilized in the SCAS digital computer. The computer central processor's circuit cards are functionally divided to aid trouble shooting. The technicians aboard expressed confidence in their ability to maintain the equipment, given properly prepared instruction manuals on both the CAS and the Varian Computer presently installed.

OPERABILITY:

The operation of the equipment was not considered difficult. Sperry provided a comprehensive slide presentation which enabled the users of the equipment to grasp all facets of its use. The large screen is easily read at night but must be shaded during the day. As was stated previously, the CRT data terminal was not easily read, in that the print was type size and could only be observed from a normal reading position immediately in the vicinity of the screen. This necessitated having the OOD walk back and forth between the CAS and CRT D/T in order to coordinate contacts and data.

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Iotron Digiplot

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This report is a description and concept evaluation of the results of Fleet experience with two computer aided collision avoidance devices. Four Atlantic and Pacific ships, including three 1052 Class Destroyer Escorts, and one Auxiliary Service Ship participated in the study. Analysis of at-sea data and observations demonstrate that the collision avoidance concept can enhance shipping safety, reduce peacetime workload of the CIC and can eliminate the need for having more than one radar repeater on the bridge.

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